REMOTE SENSING OF VERTICAL IOP STRUCTURE

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LONG-TERM GOALS

Determine under what optical conditions the vertical structure of inherent optical properties (IOP) can be obtained from remote sensing. Develop and test a model for inverting the remotely sensed radiance (R_{rs}) to determine the vertical structure of the inherent optical properties.

SCIENTIFIC OBJECTIVES

Develop a two-flow model to evaluate the conditions under which subsurface optical structure is detectable. Develop an inversion model to determine the vertical structure of the IOP based on the presence of horizontal gradients in the spectral reflectance.

APPROACH

The components of our approach are:
1. Evaluate the conditions under which subsurface optical structure is detectable,
2. Develop an inversion model to determine the vertical structure of the IOP based on the presence of horizontal gradients in the spectral reflectance,
3. Incorporate physical data and models to constrain estimates of the active surface mixing layer depth and identify regions of similar surface water properties,
4. Evaluate the model using field data.

During our first year in the HyCODE program we concentrated on the first component of the approach, namely the evaluation of the conditions under which subsurface optical structure is likely to be detectable.

The ability to use remotely sensed radiance to determine vertical structure depends on the optical properties and thickness of the surface mixing-layer (ML). In this region the physical processes are

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assumed to mix particles and dissolved materials faster than source or sink terms for the given material, which gives rise to a layer in which the optical properties can be assumed to be homogeneous. Such a layer is formed by the action of wind, waves and convection.

Light penetration through the surface layer depends on the optical properties of the surface layer and its thickness. To be detectable, stratification in optical properties must exist within the satellite viewing depth and there must be sufficient contrast between the surface layer and those beneath it. Since $R_{rs} \propto \frac{b_b}{a_t}$, no contrast will exist if both the backscattering (b_b) and total absorption (a_t) change by the same proportion between the surface and lower layers. It can be shown that the solution to the radiative transfer equation at a fixed optical depth (such as in the case of water leaving radiance) will remain constant if the IOP co-vary (i.e. a/b, a/c, b/c are constant) and the shape of the phase function is constant. We will refer to cases where the optical properties co-vary, as being vertically optically homogeneous because an equivalent homogeneous distribution of IOP exists that would provide the same reflectance. Optical homogeneity in the vertical requires that both the backscattering and total absorption increase by the same proportion, which is more likely to occur at shorter wavelengths. This is because the total absorption coefficient is dependent on the contributions by water, CDOM, and particles (phytoplankton, detritus, and sediment) and in coastal waters particles alone dominate b_b. For both b_b and a_t to change by the same proportion the optical properties must be dominated by the particles. In the red portion of the spectrum water has a large absorption coefficient and it is therefore less likely that particles will dominate the optical properties. Thus it is most likely that vertical optical homogenity will affect only a part of the spectrum.

To quantify the conditions under which we expect the spectral reflectance to be influenced by the vertical structure of the IOP we will perform a sensitivity analysis. We will start by assuming a simple two-layered system of turbid and clear water such as may be found in a river plume (turbid over clear) and over a continental shelf (clear over turbid). We will combine the structure with assumed spectral shapes for the absorption and scattering by CDOM, phytoplankton, detritus, and sediments as input into a radiative transfer model. The radiative transfer model will then be used to study the change in the remotely sensed reflectance as a function of surface and subsurface layer composition, thickness of the surface layer, optical gradient between layers, and wavelength. This study will be useful in determining at which wavelengths the R_{rs} is most likely to be influenced by subsurface structure given the vertical distribution of optical properties. We have recently used a similar approach to study the effect of the presence of thin layers on remotely sensed reflectance (Petrenko et al, 1998). A rigorous error analysis study will determine the sufficient contrast needed for the lower layer to be detectable.

WORK COMPLETED

We have obtained and began using the Hydrolight numerical radiative transfer code. We have used it to determine the expected changes in reflectance associated with internal waves using the optical properties measured during the Littoral Optics Experiment.

We are developing an analytical two-flow model with a two layer stratification in IOP to establish the sensitivity of the irradiance reflectance (R(0-)=E_u(0-)/E_d(0-)) to the contrast in the layers IOP and the mixed layer depth. The model is a standard two-flow model (e.g. Preisendorfer and Mobley, 1984) with downwelling irradiance partitioned into a direct and diffuse components. We elected to use

Haltrin's closure (Haltrin 1999 and references therein), which approximate the phase function by a delta function in the forward direction plus an isotropic diffuse component. While we expect the model to fare worst in highly turbid waters, the 1-layer version of the model has been compared with Monte Carlo simulations for a range of conditions and the errors were found to be small. In any case the model is general enough that changes in the closure can be implemented easily. The model will be compared to Hydrolight using IOP measurement collected in a wide range of conditions; from Eutrophic to Oligotrophic and from coastal to blue ocean. Varying the mixed layer depth will provide the set of conditions (ML depth, wavelength, sun illumination) for which we are likely to observe the lower layer affecting the reflectance.

We expect to present a beta version of the model in the next Hycode meeting (Nov. 1999) and provide it to other Hycode researchers. We will have two types of IOP inputs to the model. The first will require absorption and backscattering as function of wavelength, while the second will be based on concentrations of specific components (CDOM, phytoplankton, inorganic particles) in addition to water, similar to the Roesler and Perry's (1994) model. Results from this modeling effort will also be presented in the Ocean Sciences meeting in San-Antonio, TX, January 2000.

We are currently learning to use the ENVI software package for the analysis of remotely sensed images. We have access to several ocean color images obtained by the NRL's Phills sensor (the prototype of the NEMO sensor), as well as IOP data from the same environment, which we are using to refine our approach.

To test the assumptions of our proposed inversion model we participated in a cruise off Oregon during the summer of 1999. During this cruise we were able to make optical measurements in an underway mode and using a SeaSoar. The data set that was collected contains detailed 3-D measurements of the distribution of optical properties in across the continental shelf during the upwelling season. Initial results have been presented (Pegau et al, 1999) and a more detailed analysis will be presented at the Ocean Sciences meeting in 2000.

RESULTS

The shipboard and remote sensing measurements indicated that the distribution of optically important materials was temporally and spatially very complex (Figure 1). Topographic features, such as Stonewall and Heceta Banks were found to be very important in determining the horizontal distribution of optical properties by altering the alongshelf flow and also in determining the vertical distribution by mixing of optical properties when the flow interacted with these features (Figure 2).

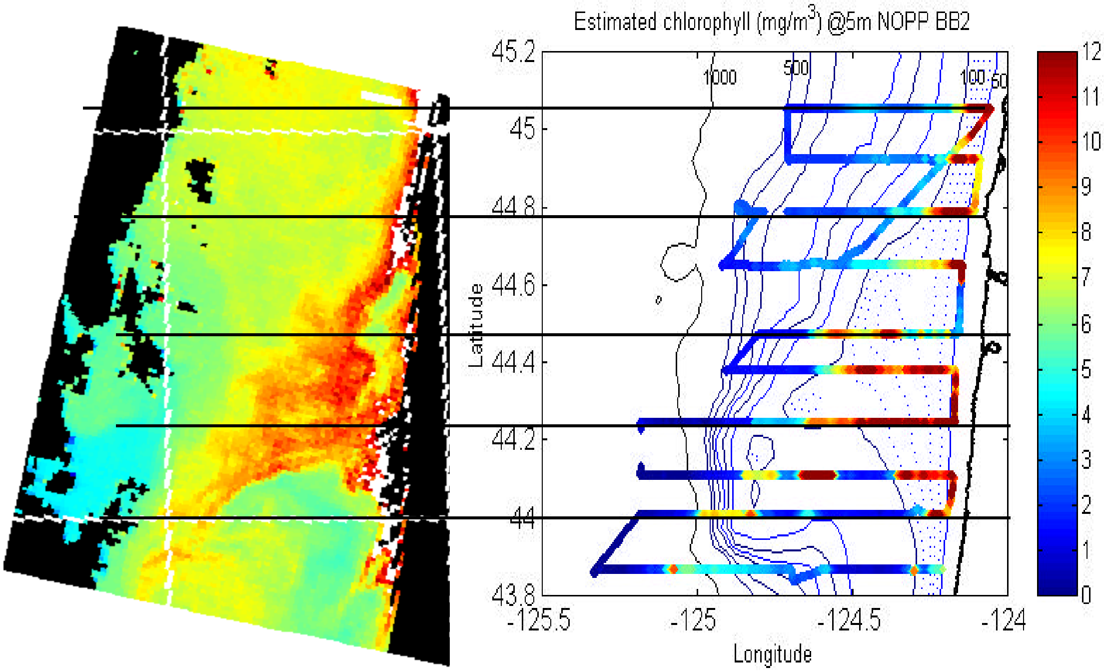

Figure 1. A SeaWiFS chlorophyll image is provided next to a survey map of the region. High chlorophyll levels are generally contained shallower than the 100m isobath. The satellite overpass occurred near the end of the 2-day ship survey (ship was ~ 44°). Differences between the satellite and ship board measurements suggest that the distribution of optical properties varied little in northern portion of the region where the shelf is narrow and varies over shorter periods south of Stonewall bank (~ 44.5°)

IMPACT/APPLICATIONS

Providing information on the vertical distribution of IOP will enable more exact inversion of ocean color to optically active water constituents.

TRANSITIONS

Data collected during the summer of 1999 was leveraged on to a NOPP sponsored research project. The data is being made available to all investigators.

The 2-layer 2-flow radiative-transfer model will be made available to the HyCODE team at the HyCODE meeting in November 1999.

RELATED PROJECTS

None

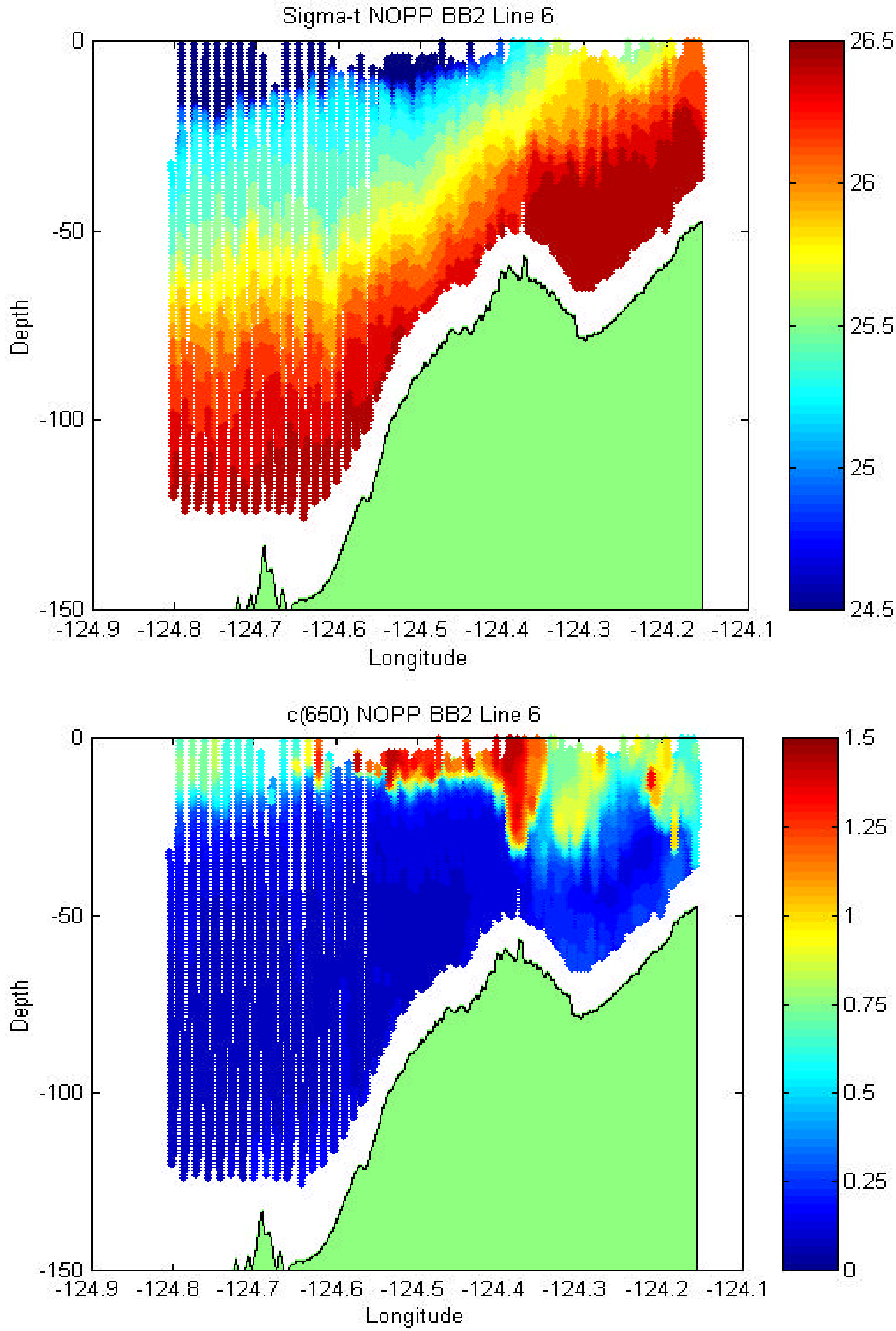

Figure 2. A vertical section of physical and optical data collected along one line of survey 4. Of note is the downward mixing of phytoplankton after the alongshelf current passed Stonewall bank. These are not contour plots but are representative of the data density.

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